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Quantum magnetotransport in the semimetal channel at the type II broken-gap GaInAsSb/InAs heterojunction

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We report for the first time the study of quantum magnetotransport in the type II broken gap p-GaIn$_{0.16}$As$_{0.22}$Sb/p-InAs heterostructures with the self-consistent quantum wells under high magnetic fields up to 16 T. The structures lattice-matched to InAs substrate were grown by the LPE method with the high quality abrupt heterointerface (d = 12 Å). Energy gap of the quaternary solid solution (E_g = 0.64 eV at 77 K) and energy band bending at the interface were determined from photo- and electroluminescent measurements. Recently the electron channel with the high carrier mobility ($u_H = (6-7) \times 10^5$ cm^2/Vs) was found out in the isotype single p-GaInAsSb/p-InAs heterojunction based on undoped quaternary layer [1].

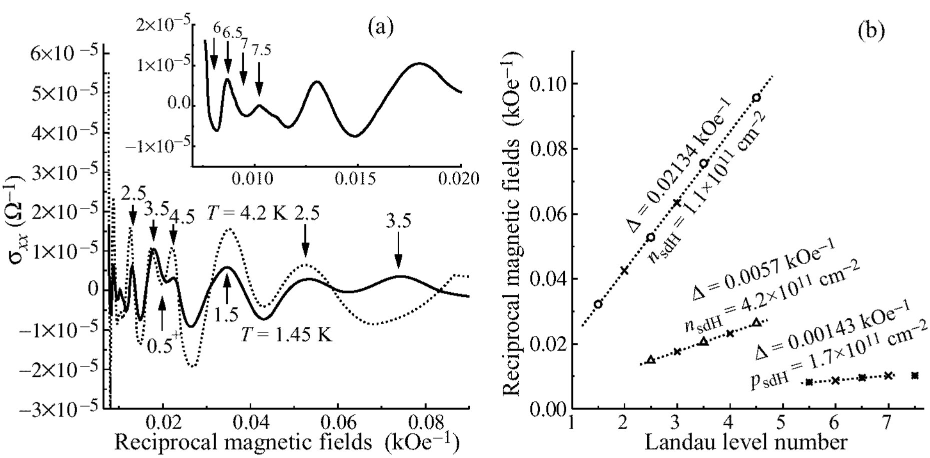

Fig. 1. Sample A. (a) σ_{xx} after the substraction of non-lineal background versus the reciprocal magnetic fields. Insert: the expanding part of the highest magnetic fields. The arrows point to the extremum positions of the oscillations. (b) The extremum positions (∘, Δ, *—maximum and ×—minimum) as the linear function of the Landau numbers.

Shubnikov–de Haas (SdH) oscillations in the Hall effect (ρ_{xy}) and magnetoresistance (ρ_{xx}) were studied at low temperatures (1.45–4.2 K) in magnetic fields up to 16 T. To identify the 2D-nature of the electrons in the channel we measured the angular dependence of SdH oscillations on the interface orientation in the magnetic field. Three groups of the SdH oscillations were observed (Fig. 1(a)). Two of them correspond two 2D-electron subbands E_1 and E_2 with the carrier concentrations $n_1 = 1.1 \times 10^{11}$ cm^{-2} and $n_2 = 4.2 \times 10^{11}$ cm^{-2},

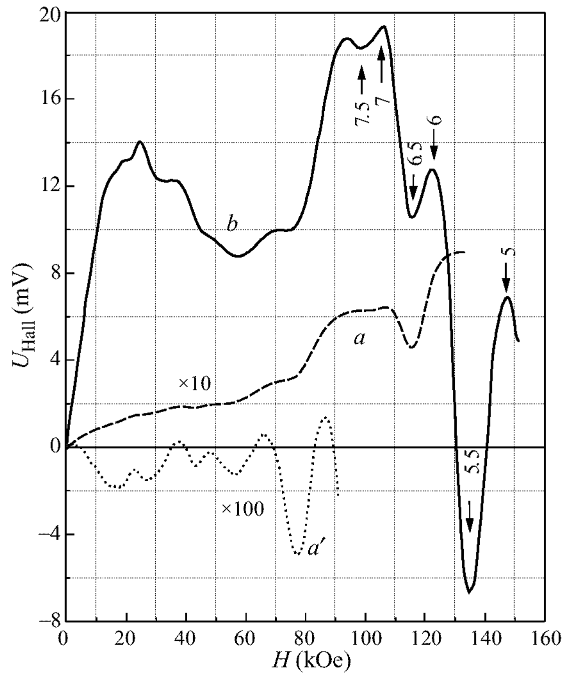

Fig. 2. Sample A. a—Hall effect voltage at $T = 1.45$ K, $I = 0.2\,\mu$A under ac condition in superconducting coil; a'—Hall effect voltage after the substraction of the non-linear background. b—Hall effect voltage at $T = 2$ K, $I = 50\,\mu$A under dc condition in Bitter magnet system. Arrows indicate SdH extremuma.

respectively, in the potential well at the p-InAs side of the interface (see Fig. 1(b)). The third period measured in high magnetic field (>10 T) can be ascribed to a hole subband with the carrier concentration $p \sim 1 \times 10^{12}\,\mathrm{cm}^{-2}$ at the quaternary solid solution side. Indeed, as shown in Fig. 2, in high magnetic fields the total Hall resistance exhibits a drastic reduction and changes a sign near 15 T. It indicates to a pronounced hole contribution into the parallel conductivity. In these magnetic fields at $T = 1.45$ K we observed also electron spin-splitting of the SdH extremum $N = 1.5$. Thus, the semimetal channel at the type II single p-$\mathrm{GaIn_{0.16}As_{0.22}Sb}$/p-InAs heterointerface determines the lateral magnetotransport under high magnetic fields.

The most impressed result is the demonstration of integer quantum Hall effect (QHE) plateaus in the Hall conductivity σ_{xy} (Fig. 3) with the total filling factor $\nu = 2, 3, 6$ in the magnetic field range according to the equations

$$\sigma_{xy} = \nu e^2/h$$

$$\nu = \nu_{eE_1} + \nu_{eE_2} - \nu_h$$

when E_1 subband moves above the Fermi level (ultraquantum limit for 2D-electrons of E_1). The transition from the $\nu = 3$ state to $\nu = 2$ state occurs through the maximum value of σ_{xy} that was not observed for the quantum well structures with one type conductivity carriers. That result is due to the crossing the Fermi level by electron and hole Landau levels simultaneously.

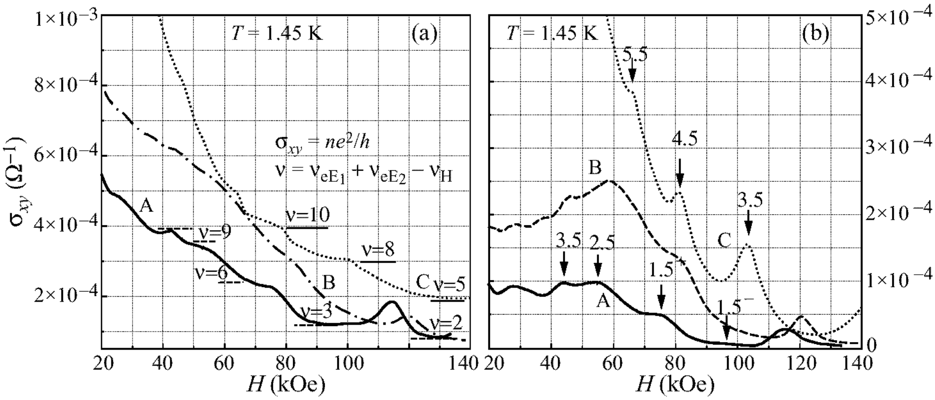

Fig. 3. The conductivity tensor components versus magnetic field for samples with the different doping of GaInAsSb layer (A—$n_{R_0} = 3.4 \times 10^{11}$ cm^{-2}, B—$n_{R_0} = 4.2 \times 10^{11}$ cm^{-2}, C—$n_{R_0} = 9 \times 10^{11}$ cm^{-2}) at $H \to 0$. (a) Hall conductivity (σ_{xy}): calculated positions of quantum Hall effect plateaus are represented for several ν values. ν is the filling factor (the number of the occupied Landau levels). (b) Dissipative conductivity (σ_{xx}): arrows indicate the crossing of Landau levels with Fermi level. 1.5^+ and 1.5^- are the result of the electron spin-splitting.

Recently the QHE was observed for the broken-gap GaSb-InAs-GaSb heterostructure grown by MBE with the same ρ_{xy} plateau numbers [2]. It is important to notice, in our case, it is the first observation of QHE in a type II single GaInAsSb/InAs heterostructure with self-consistent quantum wells grown by LPE. Thus, it is established that in the single heterostructure the plateaus on the Hall resistance can be observed under condition when only the E_2 electron subband participates in total conductivity.

Acknowledgements

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